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The Design of a Group of Plug-in Television Studio Amplifiers

by

K. J. AUSTIN, M.A., A.M.I.E.E.
(Designs Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

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FOREWORD

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THE DESIGN OF A GROUP OF PLUG-IN TELEVISION STUDIO AMPLIFIERS

SUMMARY

The monograph considers the basic operational requirements of some of the amplifiers which are used in large numbers in the television broadcasting studios and transmission network. The mechanical form of the amplifiers, which use a plug-in arrangement, is described in detail. The electrical design of the most commonly used amplifier, the video distribution amplifier, is fully described, and details of its performance, together with that of two other amplifiers are given.

1. Introduction

1.1 *General*

The amplifiers described in this paper are examples of the three types which are most frequently used both in the equipping of the originating sources of television signals, and in the network by means of which these signals are distributed on a nation-wide basis. The job which each of these amplifiers has to perform is basically simple. The distribution amplifier is required to produce a number of outputs of the video signal, each independent of the others, from a single input. A second type of video amplifier has a single output and provides a gain which maintains itself accurately at 15 dB. Its principal use is for making up the loss in the network which corrects the distortion suffered by the signal in the course of transmission over coaxial cables—usually local to a building, but sometimes providing connections between buildings. The third, the pulse distribution amplifier, provides a number of independent outputs from a single input of master timing pulses.

These basically simple requirements become complicated when the operational requirements and technical performance factors are taken into consideration, particularly in the case of the video amplifiers. The following brief consideration of the requirements shows why the particular mechanical and electrical features of the amplifiers were so chosen. This consideration will be confined to the problem of the video amplifiers since similar but simpler circumstances apply to the pulse distribution amplifier.

By far the most important fact which the designer must consider is the large number of video amplifiers which appear in tandem in the distribution chain for the television signal. The distribution chain begins at the camera output and in a large centre such as, for example, the BBC's Television Centre[1] at White City, the signal passes through many video amplifiers before leaving the building. It follows from this that the basic form of the amplifier should be such as to allow all the desired facilities to be obtained with the minimum number of amplifiers, and also that extremely narrow limits of permissible distortion must be imposed on the electrical performance of each amplifier. Clearly, in the complete transmission chain, there will be very many points at which the television signal will be required for monitoring, supervisory, and switching purposes, and it is therefore desirable that the distribution amplifier should be a high-impedance device which can be placed across the transmission line and provide branching facilities without increasing the number of the amplifiers in tandem in the main chain. It should be noted that the technique of monitoring across a transmission circuit cannot always be used because the waveform of the voltage across a coaxial cable is distorted except at the final termination following the waveform corrector. Thus, if it is required to provide a high-quality signal for monitoring at the sending end of a coaxial circuit, it is essential to insert the distribution amplifier in series with the transmission circuit. However, an amplifier with a high-impedance input will enable the number of occasions on which it must be inserted in series to be kept to a minimum.

A high-impedance connection brings with it its own difficulties because the impedance irregularity caused by the presence of the amplifier across the transmission circuit must be within the tolerable limits of distortion; it is only too easy to add additional lumped capacity greater than can be tolerated. The solution to this problem is to bring the transmission circuit as near to the grid of the first valve of the amplifier as is possible, and the technique generally adopted is in essence to run the transmission circuit physically through the amplifier as far as is practicable, with the valve providing a tapping point across the circuit. This arrangement is most inconvenient in practice unless the amplifier can be readily removed from the circuit without disturbing the wiring and, while other arrangements are possible, the one which provides simultaneously the lowest capacity and the possibility of removing it from circuit rapidly without disturbing the wiring, is to use a plug-in amplifier. Having accepted this solution to the problem, it is obviously desirable that the plug-in unit should work at fixed gain since this makes the replacement of a faulty unit quicker and more convenient, and accordingly reduces the amount of reserve equipment which must be provided. This approach to the problem therefore has led to the requirement for having a plug-in, high-impedance input amplifier of fixed gain. Another and equally powerful reason for providing amplifiers of fixed gain stems from the experience that a large operational effort is required to keep amplifiers with adjustable gain at the desired operating point. Unfortunately, both the instru-

ment used (the cathode ray oscilloscope) and the human observer using the instrument, are subject to errors of measurement which lead to inaccuracies, and obvious discrepancies then exist between signals arriving at a common point from sources which have been individually adjusted. Of course, means can be devised to make this system work satisfactorily, but there is everything to be said for abolishing the whole process and providing amplifiers of fixed gain. This assumes, of course, that amplifiers can be made sufficiently stable that their gain remains constant over the working lives of the valves, say some 10,000 hours.

These considerations, together with other major requirements of a more obvious nature, lead to the amplifiers having to meet the following requirements:

(*a*) The amplifiers must be constructed in a plug-in form having a high input impedance.

(*b*) The amplifiers must contain their own power units.

(*c*) The amplifiers must be of fixed, accurate, and stable gain.

(*d*) The amplifiers must be able to handle 405- or 625-line signals, either monochrome or N.T.S.C. colour, having a bandwidth up to 5·5 Mc/s.

(*e*) The electrical performance of the amplifiers must be such that very many can be connected in series without significant distortion.

(*f*) The amplifiers must be reliable and have a long life, say at least 10,000 hours, between valve changes.

The remainder of this monograph considers the performance requirements of the amplifiers in detail and the means whereby this performance has been achieved. In the case of the video distribution amplifier, which has the most difficult specification to meet, a detailed description is given of the design procedure and considerations.

1.2 *Applicability of Transistors*

Transistorized versions of each of the three types of amplifier have been developed, but they are at present used mainly for such purposes as feeding picture monitors, and only to a limited extent in applications which require them to be inserted directly in the transmission chain. Transistorized video amplifiers have not yet been developed to handle an N.T.S.C.-type composite colour signal and to meet, at the same time, the requirements for negligible distortion when a number of the amplifiers are connected in tandem.

2. Specification of Performance of Amplifiers

2.1 *General-purpose Video Amplifier*

This amplifier is used in several different ways. Its main purpose, as mentioned above, is to make up the loss of a long coaxial cable and its equalizer, but it is also used to provide gain and to form an output stage for some more elaborate unit. The amplifier has been designed to have a gain of 15 dB and a flat frequency response, and its one output is designed to deliver a nominal 1-volt video signal. To allow for the swings which occur when signals are cut, or change from a black frame to a white frame, and to include a margin for overload as well, the amplifier is designed to handle a sine wave of 3 volts peak-to-peak at its output before any overload effects occur. The input impedance is high, the output impedance is 75 ohms —1 per cent +5 per cent to 5 Mc/s, and the amplifier delay is 47ns. The gain is 15 dB $\pm 0{\cdot}05$ dB from low frequencies to 5 Mc/s, and the change of gain for a mains voltage change of 7 per cent or from valve ageing is less than 0·1 dB. No distortion can be seen on a wideband oscilloscope with a 625-line 1T pulse and bar test signal,[2] having a half-amplitude duration of $0{\cdot}10\mu$s. The amount of tilt introduced on a 50 c/s square wave signal with unity mark/space ratio is less than 2 per cent, and the response to d.c. and very low frequency signal variations is satisfactory. The hum level is less than 1·5 mV peak-to-peak. Although this amplifier is primarily intended to handle 1-volt video signals, it may also be used, with slight modification, to amplify pulse signals up to their zero level of 2 volts. Power consumption is 32 VA at 240 volts a.c.

2.2 *Pulse Distribution Amplifier*

This is required to repeat the pulses produced by a standard waveform generator in the central apparatus room; the four standard pulse waveforms are: line trigger, field trigger, mixed synchronizing, and mixed blanking. The pulse amplifier has a high impedance input so that several may be operated with their inputs in parallel across a single line. Each of the four separate outputs must be as independent as possible from the others in order that any subsequent operation on one output, such as an accidental short-circuit, shall have no effect on the others. This feature is referred to as the separation between outputs and is referred to in dB reduction of level. 40 dB of separation would indicate that if a signal of 1 volt peak-to-peak were fed in error into one of the outputs, only 10 mV peak-to-peak of this unwanted signal would appear across the other terminated outputs of the amplifier.

In the case of the pulse amplifier, the separation between each ouput is better than 37 dB at low frequencies and 25 dB at 3 Mc/s, and the impedance of each output is 75 ohms. The amplifier has unity voltage gain which is maintained to very close limits by its own feedback system. The rise time of the amplifier is better than 40 ns. and the low-frequency tilt is negligible on the least advantageous pulse signal it has to handle. Power consumption is 30 VA at 240 volts a.c.

2.3 *Video Distribution Amplifier*

Two versions of this amplifier exist, the AM4/503 having unity voltage gain and the AM4/504 a voltage gain of 3 dB. The construction of both is almost identical, the only differences occurring in the feedback chain in order to give 3 dB gain when required. The amplifier has an input impedance of 19 k ohms so that several may be paralleled across a single line. When six are so connected, the loss is 0·1 dB at 10 kc/s and 0·2 dB at 5 Mc/s, and this represents the maximum number likely to be paralleled in practice.

An examination of the whole network suggested that the most economical arrangement was for each distribution amplifier to have three independent outputs, and this arrangement was adopted. Each of these outputs has an impedance of 75 ohms −1 per cent +2 per cent to 3 Mc/s. The amplifier delay time is 38ns. The separation between the three outputs is better than 50 dB at low frequencies and 40 dB at 3 Mc/s in the version with unity gain. Overall feedback is used to maintain the gain at unity $\pm\cdot05$ dB from 1 c/s to 5 Mc/s. The other specification figures are similar to those for the general-purpose video amplifier. Performance details of both versions of the video distribution amplifier are given in the Appendix.

In some cases the amplifier will handle non-composite video signals, that is, signals without any synchronizing pulses present. Such signals are used in certain areas, but cannot be examined on a waveform or picture monitor until the synchronizing signals have been added. Both versions of the video distribution amplifier have provision for adding mixed synchronizing pulses to a non-composite waveform when the facility is required. Power consumption is 50 VA at 240 volts a.c.

3. Electrical Design of the Video Distribution Amplifier

3.1 *General*

The video distribution amplifier is the most frequently used amplifier, and it is found in practice that on occasions as many as ten such amplifiers are placed in tandem. It follows that the distortion introduced by each amplifier must be as small as possible if the cumulative effect is not to build up. The other major factor influencing the design is the need to get adequate separation between the three outputs. There are three basic methods of obtaining this independence between the outputs:

(*a*) In the first method, each output is provided by a separate amplifier, the input of which is in parallel with the inputs of the other amplifiers in the unit. This enables one to get any desired separation required, and the method is widely used. It suffers from the disadvantage, however, that should one amplifier fail, the others may continue to work and the failure not be noticed immediately. This is a serious matter if the output which fails is in the main programme chain, whereas the one continuing to work is providing the check monitoring. A second disadvantage is that of getting precise similarity between outputs, since each amplifier may vary from the ideal. For these two reasons it is considered that there should be a minimum of components between one output and another of the same distribution amplifier.

(*b*) The second method is to provide a large signal, for example at the anode of a valve, and provide an attenuator for each output. This gives a satisfactory separation between outputs which is not frequency-conscious and which overcomes the disadvantage of method (*a*) since in general each output is only separated from its fellows by two resistors which can have a negligible failure rate. However, it is found that in order to give each output a 75 ohms impedance, the attenuator has to have a shunt arm of little more than 75 ohms and the output stage thus has to drive current into this resistance as well as into the load resistance. This doubling of the current-handling requirement of the output stage is the main disadvantage of this method.

(*c*) The third method is to feed the outputs from a very low impedance and build each output out with a series resistance to be equal to 75 ohms. If the impedance is sufficiently low a satisfactory separation between one output and another will exist. The main difficulty of this third method is in maintaining a sufficiently low impedance over the bandwidth required. A transformer can be made to have a low output impedance but unfortunately will not cover the bandwidth. A valve operated as a cathode-follower, however, can be made to have a very low impedance which is maintained over a sufficiently wide band of frequencies.

This last variant of method (*c*) was the one adopted. The advantage of only having to provide half the output current of method (*b*) is apparent when it is realized that even with method (*c*) the output stage draws almost twice as much current as the rest of the amplifier.

In order to get a separation of 50 dB at low frequencies falling to 40 dB at 3 Mc/s, the output impedance of the amplifier must be less than 0·5 ohms. This low output impedance cannot be obtained merely by using a suitable high-mutual-conductance valve as a cathode-follower. It is necessary to reduce the impedance still further by using overall negative feedback, and this also enables the requirement of extremely low distortion to be satisfied. The amplifier was accordingly designed with a cathode-follower output stage and overall negative feedback taken from the output stage cathode to the input of the amplifier.

Shortly after design work on this amplifier had commenced, a very suitable valve for use in the output stage became available in Great Britain. This was the S.T. & C. triode type 3A/167M, now coded CV5225. With a standing current of 40 mA, this valve has a rated mutual conductance of 47 mA/V. It was apparent that not only would two of these in parallel provide enough current to drive three outputs, but also that if each valve were operated with a g_m of about 40 mA/V, the output impedance of the pair would be only 12·5 ohms. This pair of valves was preceded by two amplifying stages, and by applying overall negative feedback from the output cathodes to the input of the amplifier, the output impedance was reduced to less than 0·5 ohm.

About 32 dB of overall negative feedback is necessary to achieve this. With this order of feedback, the response of the amplifier within the normal frequency range is excellent and the whole problem resolves itself into that of getting satisfactory low-frequency and high-frequency cut-off characteristics. Although the two ends of the frequency

spectrum can be treated independently, it is best to tackle the low-frequency performance first, since the components used here can affect the high-frequency end. The amplifier will first be described briefly and then the factors affecting the low- and the high-frequency ends of the cut-off characteristic will be described.

The circuit diagram is given in Fig. 1 (pages 10 and 11) and the performance achieved is given in the Appendix. It can be seen that the amplifier is basically a triple with a cathode-follower output stage. The input signal is applied to the grid of V2 and amplified. V3 provides further gain and drives the output stage. This consists of two cathode-followers in parallel, the output from their cathodes being fed via 75-ohm resistors and low-pass filters to the three output terminals. At the same time, negative feedback is taken from the cathodes of the output valves back to the cathode of V2. The ratio of R34 and R35 to R18 is adjusted to give unity gain. Valve V1 is used to add synchronizing pulses to a non-composite main signal if required. The synchronizing pulse signal is inverted and fed into the cathode of V2.

In the self-contained power supply, the main rectifier ring MR1-4 feeds the output stage which takes 60 per cent of the total current. A further rectifier provides a higher voltage to work a simple cathode-follower stabilizer V8, which provides the h.t. supply for the first two stages of the amplifier and the synchronizing pulse inverter stage.

3.2 *Low-frequency Performance*

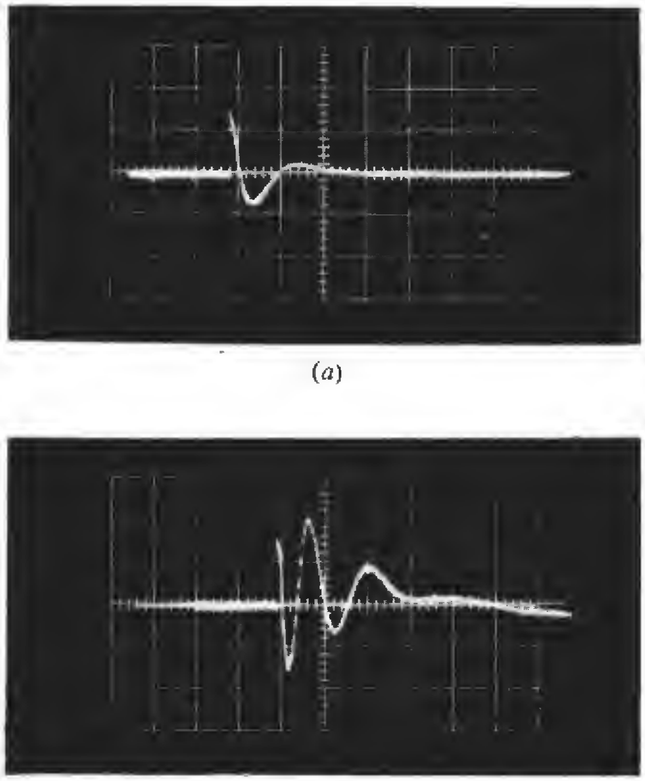
The specification for the amplifier states that the sag or tilt on a 50 c/s square wave of unity mark/space ratio shall not exceed 2 per cent of the mean square-wave amplitude. In addition to this, the amplifier must have a satisfactory response to a sudden d.c. change in the signal applied to it. The reasons for this second requirement are as follows: certain types of film can produce a completely black frame, followed by a completely white frame or vice versa, which produces a d.c. step in the output signal. Since the distribution system does not transmit d.c., this step is modified by the first amplifier following the telecine machine which has generated it, and is further modified by each subsequent amplifier in the distribution chain. When a step function of this type is applied to a complete amplifier, the output signal almost always shows an overshoot. This overshoot depends upon the number of time constants in the amplifier and their relative spacings in frequency.

It is not by itself sufficient to design for a small overshoot on one amplifier, since each amplifier modifies the step function and passes to the next one a signal different from that applied to it. Fig. 2 shows the effect of a d.c. step function signal on a cascaded string of (*a*) two and (*b*) five amplifiers of an unsatisfactory design. It can be seen that the first overshoot builds up rapidly to a signal of large magnitude and that second and third overshoots follow suit. The large amplitude of overshoot causes following amplifiers to overload and further distortions follow.

There is a design difficulty in that it is not immediately possible to predict from the response of one amplifier to a unit d.c. step what the response of several amplifiers in cascade will be. A test has been evolved, however, which is of greater value than one involving a single d.c. step. The test consists of generating a d.c. step signal and passing it through the time constant formed by a condenser and resistance in series. The value of the condenser is changed so that the decay of the original step may be varied in stages between 5 seconds and 1/100 second. The test signal is applied to the amplifier's input and with each different signal the overshoot produced by the amplifier is noted. The designer's aim is to ensure that all the overshoots produced by these test signals are at a low level with no peak caused by any one of the signals. This test procedure was used with this amplifier.

Fig. 3 shows what happens with (*a*) five and (*b*) ten amplifiers of this design in cascade. The first overshoot reaches a known value and does not increase, and second and third overshoots have not built up alarmingly even after ten amplifiers in cascade have handled the signal.

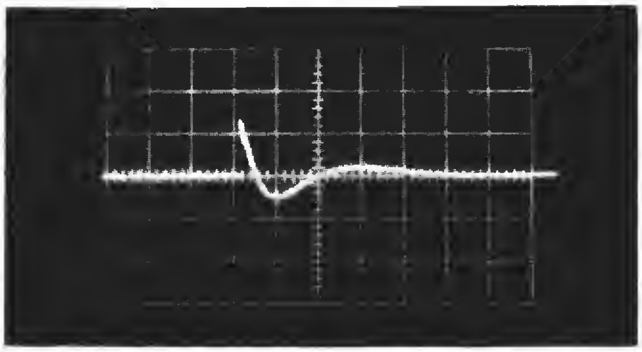
Generally speaking, the fewer circuits involving time constants in the amplifier the better the step response will be. This amplifier, as can be seen, has three low frequency time constants in the main loop and one, the input coupling, outside it. The interstage couplings between valves are



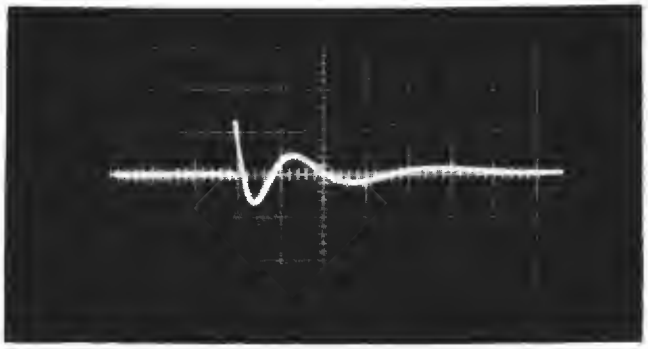
(*a*)

(*b*)

Fig. 2 — Overshoot following a step function applied to (*a*) *two and* (*b*) *five video distribution amplifiers of unsatisfactory design in cascade.*



(*a*)



(*b*)

Fig. 3 — Overshoot following a step function applied to (a) five and (b) ten video distribution amplifiers, type AM4/503 in cascade.

of the compensated type and if perfect give no change of gain or phase with frequency. In fact, even if the compensation is not perfect, their crossover occurs at such a high frequency that any departures of phase shift or gain are made negligible by the full feedback existing at the crossover frequency.

There are two time constants which have an ultimate phase shift of 90°. The first exists at the cathodes of the output valves where a total capacitance of 4,000 μF feeds an effective resistance of 50 ohms. The second time constant occurs in the feedback connection and is formed by a capacitance of 5,000 μF feeding the cathode load of V2 through a 270 ohms resistance. It is necessary to have both of these since the capacitors must be present in each case so that there will not be a standing d.c. on the output of the amplifier.

There is a further time constant in the cathode of V3. Here 100 μF feeds the cathode impedance of the valve, but this time constant, although in fact it produces an ultimate loss of 30 dB, does not produce any ultimate phase shift. The phase shift increases to a value of about 70 degrees and then returns to zero with progressive lowering of frequency. By suitably choosing this time constant, the reduction of phase shift towards zero can occur when the phase shift of the output coupling time constant is increasing and the total phase shift kept substantially constant for several octaves. Fig. 4 shows the complete Nyquist[3,4] gain-phase relationship for the amplifier. This loop was measured by breaking the amplifier at the grid connection of V3. It can be seen that a low-frequency phase margin of about 70° has been achieved from a gain of 20 dB at 5 c/s to a loss of 12 dB at 0·2 c/s. This margin is extremely good from the Nyquist stability criterion point of view and is responsible for the very good step response. In order to get the time constants suitably spaced, it was necessary to use very large coupling capacitors, in particular C12 and C17, which are 2,000 μF 50 volts working, and C13 which is 5,000 μF 6 volts working. Because each of them works at a point of low impedance, these condensers had to be of very low inductance and suitable electrolytic capacitors were developed for this purpose.

Although the three main time constants are thus formed by electrolytic capacitors of wide tolerance —20 per cent to +50 per cent of nominal capacity—changes in value of these capacitors within these limits have a negligible effect on the 50 c/s phase response or on the response to low-frequency step signals.

The interstage coupling between V2 and V3 is slightly modified from the ideal form to reduce the phase shift at 50 c/s. This accounts for the slight increase in gain at about 50 c/s which may be observed in Fig. 4.

The self-contained power supply uses resistance capacity smoothing only. Since there is 32 dB of feedback at 50 and 100 c/s, the amount of hum produced on the output is greatly reduced and is well under the 1 mV peak-to-peak required by the specification.

The main rectifier ring uses germanium junction rectifiers. These are very reliable, cheap, and most suited for a low-power application of this nature. The output stage uses the smoothed output of the rectifier ring directly, drawing about 70 mA at 175 volts h.t.

Since the amplifier has its first two stages directly coupled, any bump on the h.t. rail due to a mains fluctuation is passed directly to the output valves. This bump can occur at a frequency which is too low for any reduction in amplitude to be brought about by the overall feedback. For this reason the first two valves are operated from a cathode-follower stabilizer which effectively removes mains fluctuations appearing on its anode. The load taken by the first two valves is constant and thus to a first approximation they are fed from a constant-potential h.t. rail.

3.3 *High-frequency Performance*

The problem at the high-frequency end of the spectrum is entirely that of first obtaining a satisfactory frequency response to 5 Mc/s, and then tailoring the cut-off characteristic beyond this to give a satisfactory Nyquist stability margin. The amplifier has two main interstage circuits with high frequency time constants, each giving 90° ultimate phase shift. The cathode-follower output stage gives a further 90° ultimate phase shift, although the 45° phase shift point is much higher in frequency than in the case of the interstage time constants.

Maximum gain up to 5 Mc/s and minimum phase shift

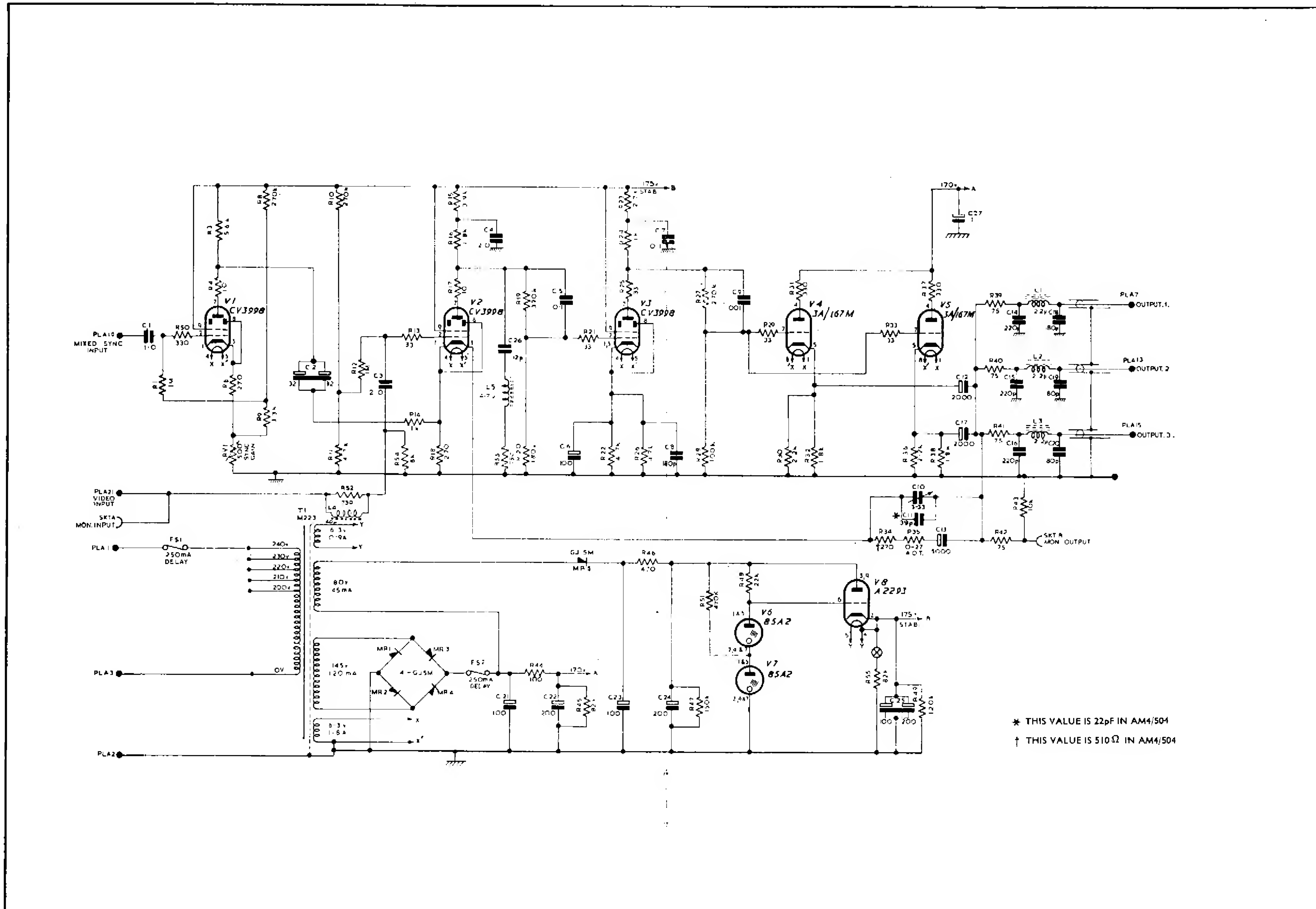


Fig. 1 — *Circuit diagram of the video distribution amplifiers, types AM4/503 and AM4/504.*

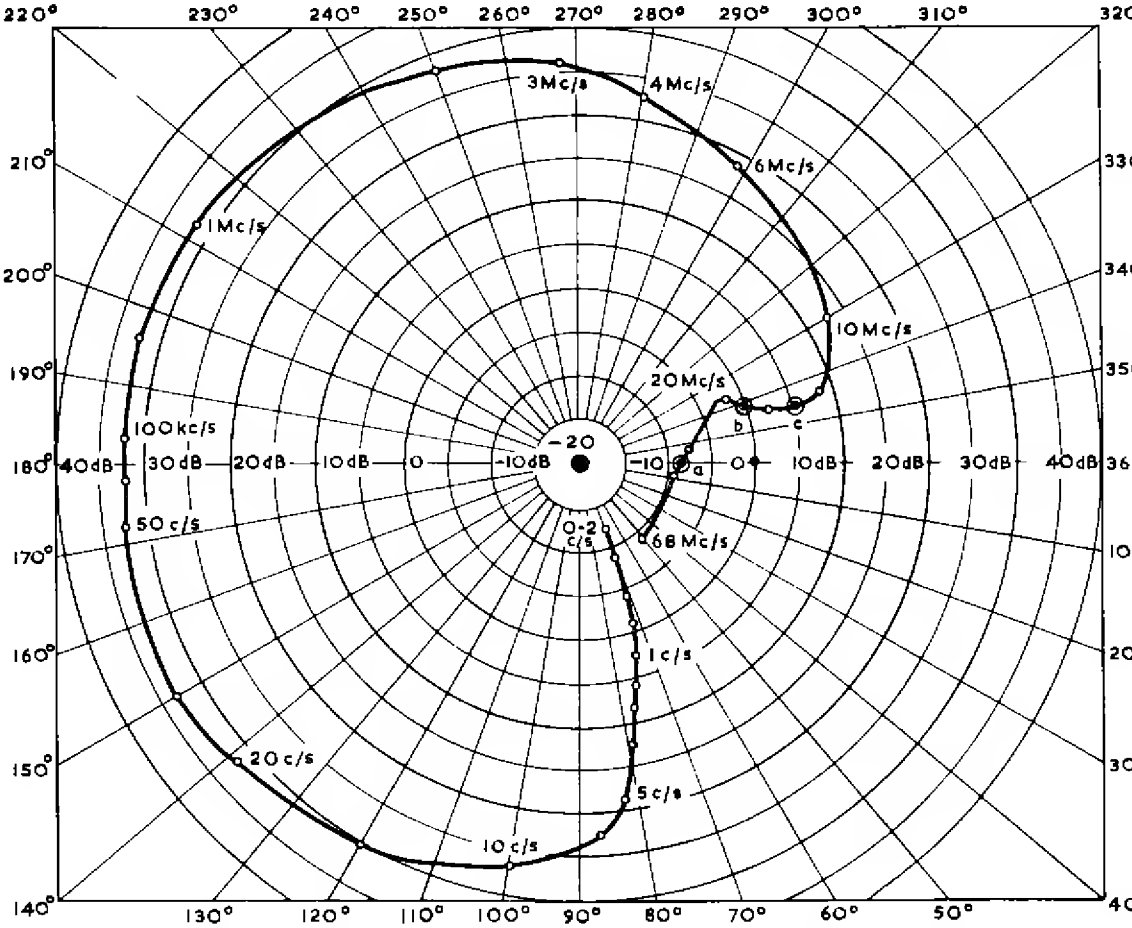


Fig. 4 — *Nyquist stability curve for the video distribution amplifier from* 0·2 *c/s to* 68 *Mc/s.*

is obtained by using valves with the best figure of merit available. The valves used are beam tetrodes type CV3998 and have a mutual conductance of 16·5 mA/V when drawing 13 mA of anode current. They are repeater valves and are extremely reliable. In the interest of maximum gain and minimum phase shift, it has not been possible to adopt the usual expedient of arranging the high-frequency time constants to be several octaves apart. Neither was it found possible to fit anode loading coils to the interstage couplings and at the same time obtain a satisfactory Nyquist stability margin.

Reference to the gain/phase-shift diagram, Fig. 4 ,will show that from a medium-frequency feedback of 32 dB, the feedback available drops to 26 dB at 3 Mc/s and 18 dB at 5 Mc/s. This causes the output impedance of the amplifier to rise with increase in frequency and is the main reason for the reduction in separation between outputs. However, the figures obtained are satisfactory. With the degree of feedback remaining at 5 Mc/s, the gain stability of the complete amplifier with changes of mains voltage or valves is excellent. The frequency response is also excellent as indicated in the specification.

Once the amplifier has a satisfactory performance to 5 Mc/s, the problem remains of arranging the cut-off to give a satisfactory Nyquist stability margin. Points of particular concern are (*a*) the gain margin at 180° phase shift, (*b*) the phase margin when the loop gain is 0 dB, and (*c*) the minimum phase margin above point (*b*). The margins shown on Fig. 4, which is the plot of a representative amplifier, are 8 dB at point (*a*), 24° at point (*b*), and 14° at point (*c*).

These margins are considered satisfactory; the margin at (*a*) because the maximum g_m obtainable from the valves in practice only reduces this margin by about 2 dB, and the margins at (*b*) and (*c*) because with a controlled layout of components the phase shift is very constant from amplifier to amplifier and never varies more than ±2° from the sample shown. However, in order to obtain these margins, several different measures have been taken and will be described.

The gain of the amplifier from input to output is determined by the ratio of R34 + R35 to R18, and this gain is made unity at medium frequencies. At high frequencies the stray capacity across R18 becomes significant and may be

balanced out by a trimmer across R34 + R35. This trimmer may be used to over- or under- compensate the coupling; it is in fact adjusted to give the most level response up to 5 Mc/s during initial line-up of the amplifier. The circuit does, however, give an advantageous phase shift beyond 5 Mc/s.

There is an interstage shaping network R53, L5, and C26 across the anode load of V2. This network series resonates at 21 Mc/s and modifies the Nyquist curve in regions (*b*) and (*c*) to improve the stability margins.

Each output resistor feeds the line through a low-pass filter, which cuts off at 12 Mc/s and isolates the amplifier from the line it feeds above this frequency. If one output is accidentally unterminated, an open-circuited length of line is usually left still connected. The impedance of this line in series with 75 ohms appears across the valve cathode point. At 16 Mc/s for example, the cathode impedance is quite high and the presence of this line impedance would lower the phase margin below an acceptable level. In addition to making the stability margin independent of whether the amplifier is terminated or not, the filter on each output also limits the amplifier gain at frequencies above 5 Mc/s. In the absence of a filter, the gain rises about 1·5 dB at 15 Mc/s, but with the filter present it falls off smoothly above 5 Mc/s.

This amplifier has to operate with its input in parallel with several others since the specification calls for as many as six to be operated in parallel across one line. This presented a problem since the input impedance can become negative and it was found that with several in parallel instability would occur at about 25 Mc/s. This was cured by fitting a 0·5 dB pad formed by R52 and R54 across the input to the amplifier. This gives the amplifier an input impedance of 19 k ohms. To avoid a loss of gain at frequencies lower than those at which input impedance troubles occur, R52 is shunted with a 40 μH coil L4.

3.4 *Additional Design Points*

There are a further number of points not specifically connected with the low or high frequency performance which can be mentioned. The first valve of the amplifier acts as a synchronizing pulse adding stage. Synchronizing signals of 2 volts amplitude applied to the grid of V1 are inverted and fed into the cathode of V2. The load of V1 is the cathode impedance of V2 in parallel with R18 and the feedback network. This method of injecting the synchronizing pulses enables the input to the synchronizing adding stage to be high impedance. Since overall feedback may not be used on this stage, and to allow for variations in the amplitude of the synchronizing pulses incoming, a gain control is provided to allow the level of pulses to be accurately adjusted. Of course, synchronizing pulses are only added in this way when it is desired to display the signal on a picture or waveform monitor and extreme precision of synchronizing pulse amplitude is not required.

The whole performance of the amplifier is dependent upon the existence of sufficient negative feedback, which is in turn dependent upon the forward gain remaining high. In order to achieve this, the amplifying valves V2 and V3 are operated with d.c. feedback. This helps to maintain the cathode current constant, which in turn helps to keep the mutual conductance, and hence the stage gain, constant also.

When the valve type CV3998 first became available, a batch of fifty were selected at random from the various makers and a life test commenced. The valves were operated in conditions identical to those in the amplifier and were switched on for $11\frac{1}{2}$ hours out of every 12; the half-hour when they were switched off enabled the panel on which they were mounted to cool down almost to the ambient temperature. By 1961 the valves had each completed over 25,000 hours and none had suffered catastrophic failure. Periodic measurements of mutual conductance showed that only three valves had dropped below the makers' suggested end-of-life figure of 11 mA/V at 13 mA anode current.

The design of this amplifier has formed the basis of several subsequent amplifiers performing different functions. In particular, the general-purpose amplifier is almost identical but has a different ratio of resistors determining the feedback ratio to give a forward gain of 15 dB. Since only one output is required, only one output valve is used.

All these amplifiers have been built with the main emphasis on reliability. Electrolytic capacitors are run well below their temperature limit and with very much less than the rated ripple current flowing. Resistors are operated at half or less of their rated dissipation. The rectifiers are operated well below their current and peak inverse voltage ratings.

4. Mechanical Arrangements

The main requirement for the new range of amplifiers was that they should be of 'plug-in' construction to assist the rapid replacement of a faulty unit. A plug-in chassis was designed for this purpose and a typical unit is shown in Figs. 5 and 6. This particular unit is the video distribution amplifier.

The chassis is formed from two main hoops of a cold bending aluminium alloy to which are fastened the chrome plated steel handles. A steel panel forms the front of the unit and carries the main part of the amplifier. All valves project forward and conventional wiring is used to connect the valve bases and the other components mounted behind the front panel. All earth connections are made directly to solder lugs punched in the steel panel. A metal sheet mounted across one of the two main loops towards the rear of the unit carries the power supply. A sand-cast aluminium alloy block joins the two main hoops of the chassis rigidly together, and all electrical connections to the amplifier are made through a single 24-way plug carried on this casting. When the plug-in chassis slides into its housing, two guide holes in the casting locate on two guide pegs mounted in the housing. In addition to the main guide holes, there are two further index holes on the casting which identify the type of unit carried on the plug-in chassis. These index holes are drilled in different positions for different units, and mating pegs are mounted on the housing into which the unit is plugged. This is a safety de-

vice to ensure that only the correct type of unit may be plugged into any particular housing. If an incorrect unit is pushed into the housing, it will only enter part way before one of the index pegs strikes the casting in an undrilled position and prevents the unit from being pushed home.

A unit is retained in place in its housing by a screw which is operated by the knob carried on the spindle projecting from the front panel. This spindle carries a bush which bears on the rear casting and pulls it and the 24-way plug firmly into engagement with the mating socket at the back of the housing. The plug itself has been given a small amount of float to allow easy engagement.

The mains are brought into the unit through three pins at one end of the 24-way plug, and the rest of the pins are used to carry the video input and output connections. The centre row is earthed and alternate vertical rows are also earthed. By this means very low crosstalk figures are obtained between the active pins to which the coaxial centre conductors are connected.

Maintenance is intended to be carried out with the unit on a test bench and the unit is completely open, as can be seen. The unit normally stands on its two handles for maintenance, so these handles serve the purpose of protecting the unit, enabling it to be carried easily from place to place, and of withdrawing and replacing the unit from its housing. The plug-in unit may be rested on any of its six faces without damage to components.

The majority of the equipment being used for Television Centre is not force-cooled and care has therefore been taken in the design of units to see that they can dissipate their heat satisfactorily without any local 'hot spots' developing. All the valves, which are the hottest components, have been mounted on the front panel facing forward. As the front of the unit is open, there is a moderate flow of air

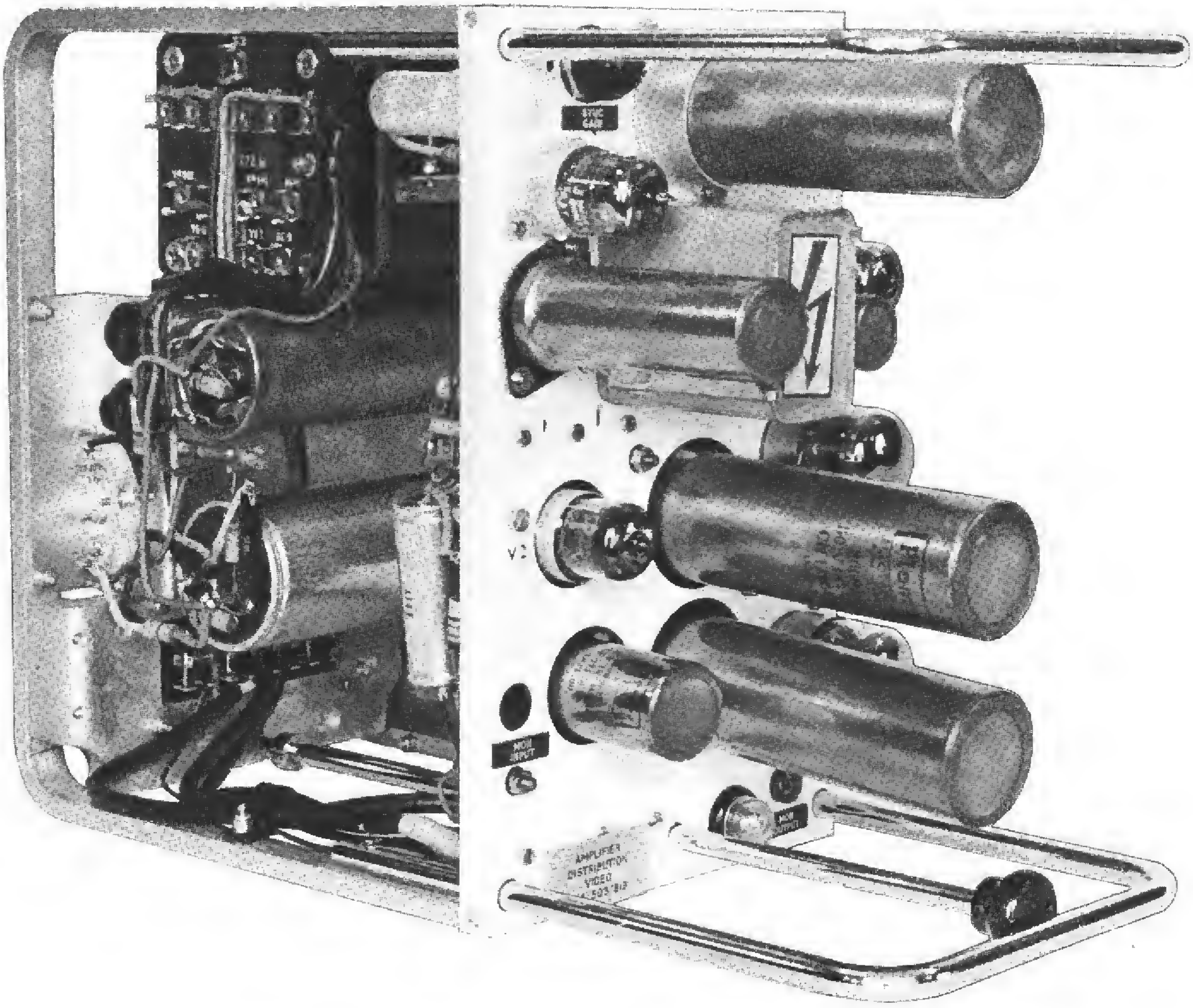


Fig. 5 — Front view of the video distribution amplifier, type AM4/503.

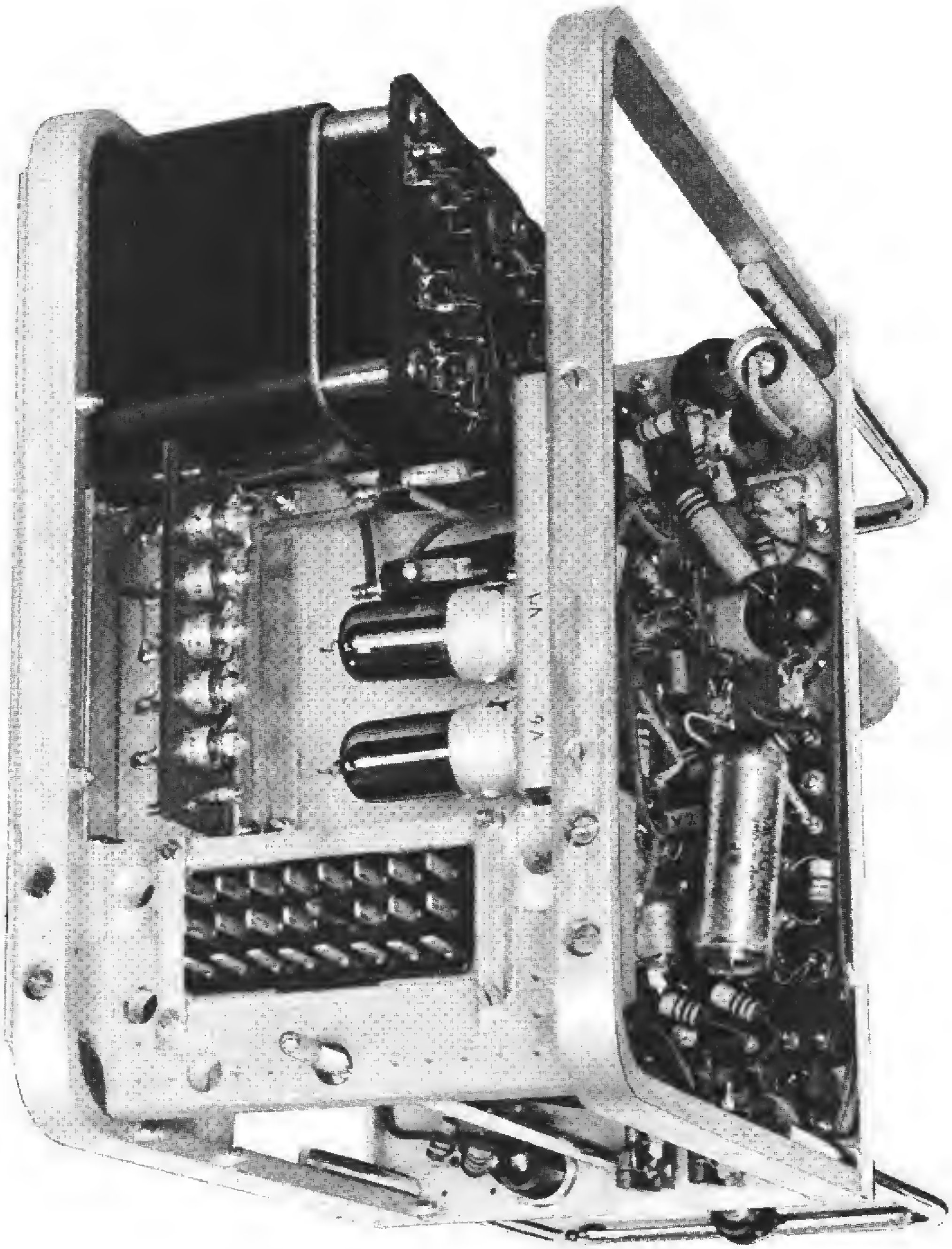


Fig. 6 — Rear view of the video distribution amplifier, type AM4/503.

past it. The front of each unit is painted white so that radiated heat from the valves will be reflected away from the chassis. To help the chassis to keep cool, the housing for the plug-in unit is open at top and bottom, and, since the unit itself is also of an open construction, there is a clear air passage from the bottom to the top of the bay. This helps to remove the heat from resistors and other dissipative components mounted behind the front panel. Care has been taken in the design of all the plug-in units to ensure that this air channel is not obstructed by any very large component or bracket fixing. An analysis of the heat lost in the particular unit photographed shows that 66 per cent is dissipated by valves, 7 per cent by resistors mounted just behind the front panel, 14 per cent by transformer loss and 13 per cent by resistors mounted in the power pack. Tests have been carried out with a bay full of units having the

maximum dissipation envisaged, which is about 50 watts per unit (or about 1 kW per bay) and the maximum chassis temperature rise on any unit has been 18°C above ambient. This is very satisfactory since the temperature rating of the front panel mounting electrolytic capacitors is 71°C for some types and 85°C for others. Ventilation of the power supply components is not as thorough as the main chassis components, but since the dissipation here has been kept low, the temperature rise for the back of the unit is not as great as for the front panel.

The majority of the amplifiers built on these chassis are of fixed gain and thus have no gain control on the front panel. They rely on overall feedback to keep their gain constant. In the event of a failure, the unit is withdrawn and replaced by a new unit as quickly as possible. Input and output monitor points on the front panel enable a unit to be quickly checked.

The unit itself plugs into a panel which can carry three units in a vertical bay space of $10\frac{1}{2}$ in. This panel mounts on a normal 19 in. bay or in a cabinet. Fig. 7 shows one of these panels with one space containing a plug-in amplifier, one empty, and one carrying the blank panel normally used with an empty housing. The plug-in unit is carried on runners which can be seen in the empty housing. The rear surface carries a sub-panel on which are mounted a 24-way socket, two guide pegs, and two index pegs. This sub-panel is accurately located, with respect to the runners on which an amplifier will slide, by means of a jig used during assembly of the complete housing. It is thus not necessary to build the complete housing to very accurate limits. Amplifiers are screened from each other by the vertical panels between the individual positions, but in the interest of bay ventilation, there is no screening at the top or bottom. There is space available for a mesh to be fitted at the bottom of each housing should this be considered desirable on any future occasion, but this has not yet been found necessary from the crosstalk point of view.

A close-tolerance coaxial cable, which has been developed for carrying the video signals, has a solid inner conductor, a layer of polythene dielectric material, two outer stranded copper braids and a layer of P.V.C. as an outer cover. Special arrangements have been made to terminate this cable on the rear housing of the amplifier frame. Fig. 8 shows a connector sub-panel which has been partially wired. The ability to remove this sub-panel for wiring simplifies the installation engineers' problem of making connections to units located either high up or low down on a bay.

It can be seen that a metal ferrule is provided to take each coaxial cable connection. After the cable end has been prepared, it is inserted into the ferrule so that the copper braids ride up over the ferrule. The 'O' clip is then slid for-

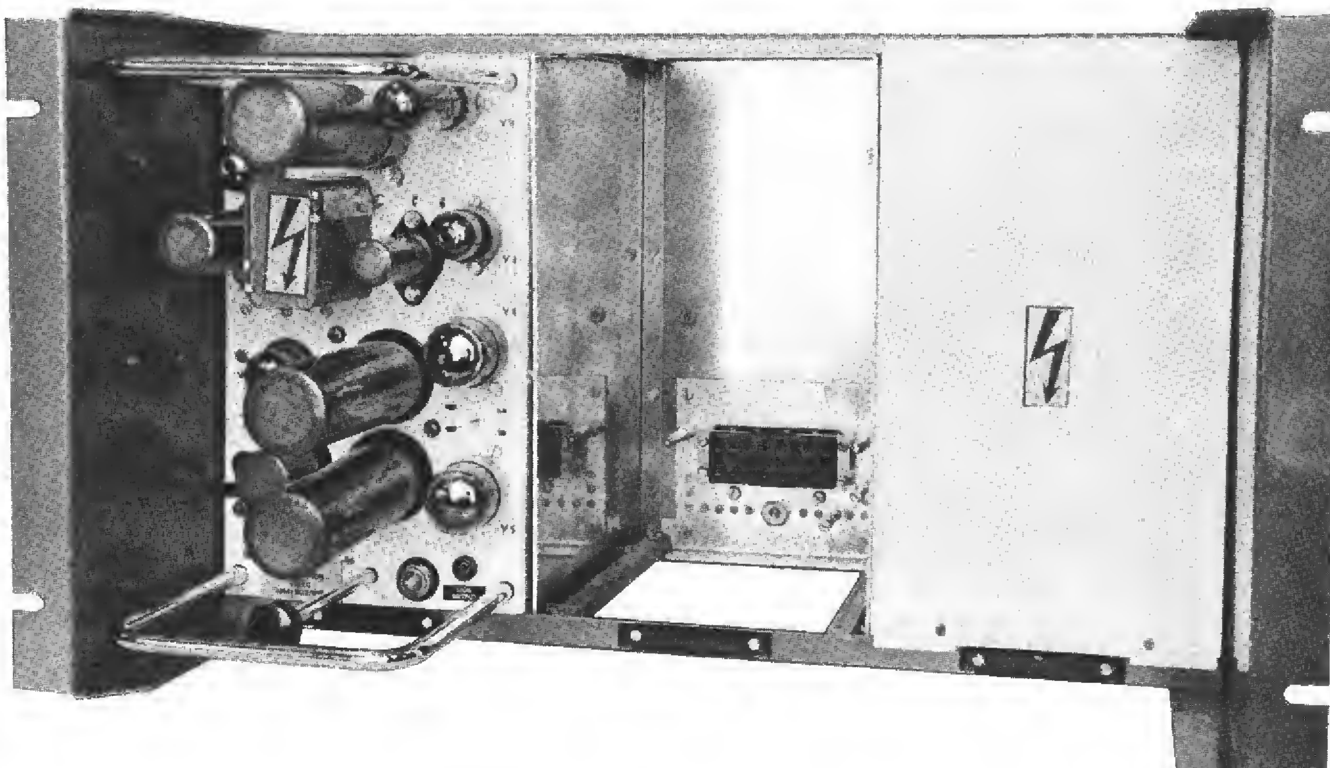


Fig. 7 — Mounting frame with one amplifier installed, one open space, and one blank panel.

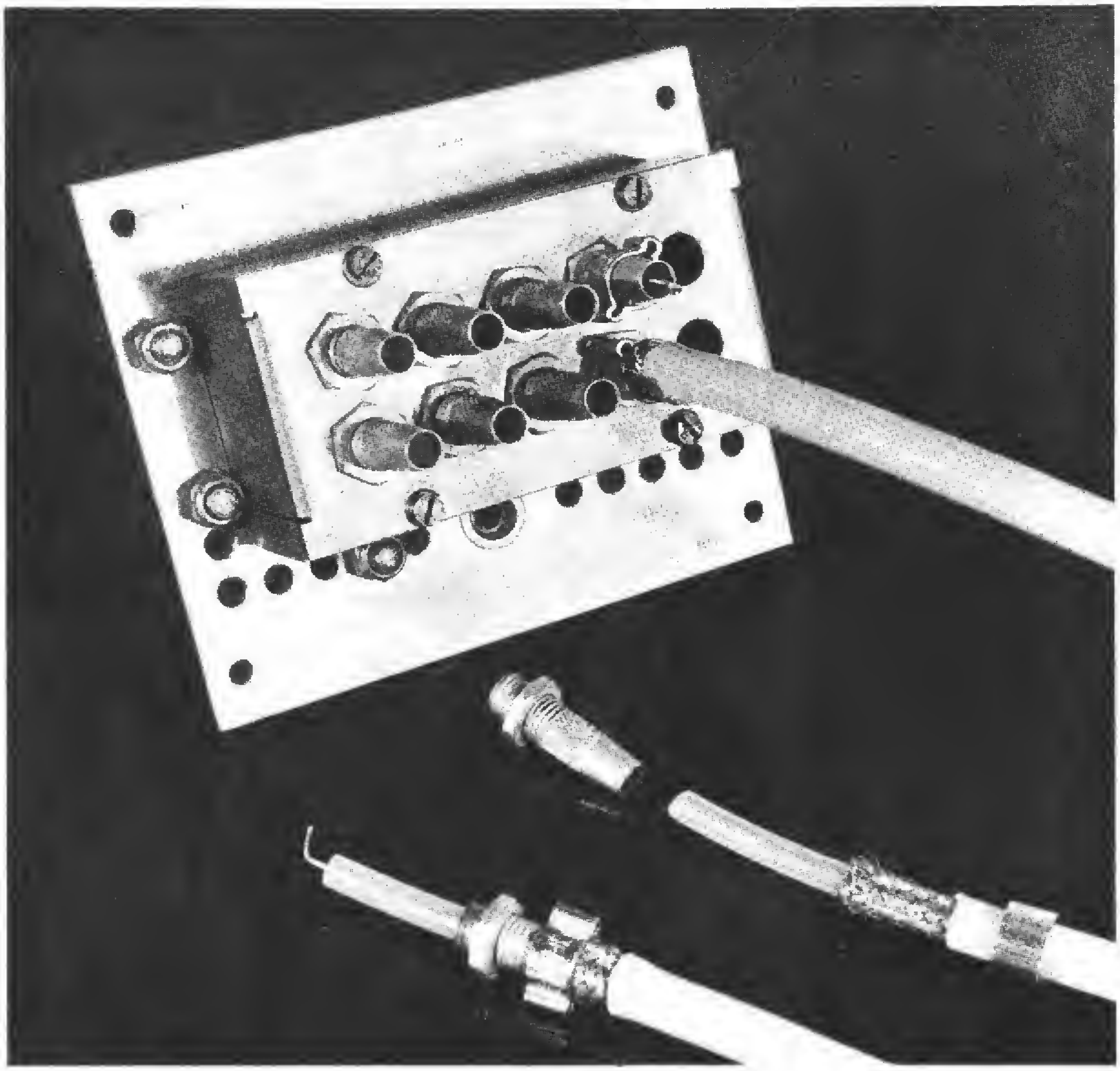


Fig. 8 — Rear connector block showing method of connecting coaxial cable.

ward to cover the braid and subsequently crimped with a special tool to make a permanent connection. The inner conductor of the coaxial cable is soldered to its appropriate pin in the usual manner.

Coaxial inner conductors on the bottom row are only connected to bottom row pins, and top row cables are only connected to top row pins. Between the two layers of cables, small pieces of copper wire are connected to take the earth directly across between the ferrules and the centre earthed row of pins on the 24-way connector.

This system of crimping ensures that good mechanical and electrical connection is made between the earth of the chassis and the braid of the coaxial cables. Alternative systems which use a soldered braid connection introduce the risk that the polythene dielectric can be melted and the clearance between inner and outer reduced without any external sign of damage becoming apparent.

This cable crimping arrangement provides facilities for joining eight coaxial cables to each amplifier. No amplifier has more than four outputs so that four cable holes are thus left for input purposes. The input connection holes are arranged in pairs at the right-hand end of each row. If the amplifier is to have its input terminated, only one input cable is used and the 75 ohms resistor is wired directly from the input pin to earth. There is space in the ferrules to contain this terminating resistor. If the input to the amplifier is to be regarded as high impedance, the input cable is wired to the input pin through one cable hole and then wired out through the adjacent hole of the input pair, and continues on to its ultimate destination.

The left-hand ferrule in each row is reserved for the mains cable to each unit. The cable used is screened and the screen is crimped to the ferrule in the same way as the braid of a coaxial cable is treated. The top ferrule carries the incoming mains cable, which has mains and neutral wires joined to the appropriate pins on the 24-way connector. The bottom ferrule carries the outgoing mains cable which is wired to the same pins and then carries the mains supply on to the next unit. The cable rating is 2 amps and thus six or nine amplifiers, according to power consumption, can be run from one power point. Each amplifier is individually fused and the power supply point is also fused.

This method, which uses one multiway connector to carry in video and mains cables, has proved very successful. Crosstalk between adjacent coaxial leads is better than 70 dB at 5 Mc/s and the crosstalk improves rapidly as the frequency is lowered. In addition, the discontinuity caused on a long coaxial cable by bridging a connector of this type across it, even with an amplifier *in situ*, cannot be detected with a $0 \cdot 10$ μsec. pulse.

The equalizer used to make the loss of a length of cable equal to 15 dB and independent of frequency can be mounted in a die-cast box immediately above the cable terminating panel. The input coaxial cable is wired directly into the equalizer box. The equalizer output is wired back to the input ferrule on the cable terminating block. The equalizer itself is of printed-circuit form and lies in the die-cast box parallel to the back surface of the amplifier housing. The lid of the die-cast box may be easily removed to gain access to the equalizer.

In addition to the range of plug-in amplifiers with self-contained power supplies designed to fit in the 3-space panel, several power supply units have been constructed on the plug-in chassis. They are designed to provide h.t. supplies for other apparatus not described in this monograph. When a power supply unit is fitted in a housing, the same cable fixing arrangement is used but the coaxial cable is replaced by the screened mains cable which is used for mains wiring purposes.

5. Conclusion

The range of amplifiers described in this monograph meets the requirement for a reliable and easily-replaceable television studio amplifier, with stable gain and frequency response, as well as other performance details conforming to a strict specification. The basic amplifier circuit uses three stages with overall negative feedback, and is mounted in a plug-in unit with built-in power supply.

Well over a thousand of the amplifiers are now in service. Their gain stability has proved in practice to be extremely good so that the differences in signal level at various parts of a complex network are no longer significant, and the excellent frequency response enables good 'K' ratings to be achieved over the longest chains of amplifiers. The mean period of service between failures is over 10,000 hours—equivalent to about two years' normal running. Valves and electrolytic capacitors account for about 85 per cent of such failures as do occur.

6. Acknowledgment

Acknowledgment is made to members of the BBC Designs Department who co-operated in developing the amplifiers described in this monograph.

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APPENDIX

PERFORMANCE DETAILS OF THE VIDEO DISTRIBUTION AMPLIFIERS

Figures apply to both types unless otherwise stated

Power Supply

Mains input, 50 VA at 240 volts 50 c/s a.c.

Impedances

Input impedance, 19 kilohms.
Output impedance, 75 ohms -1% $+2\%$ to 3 Mc/s.

Levels and Gains

Normal output level, 1 volt peak-to-peak on composite video signal.

Overload point, 3 volts peak-to-peak on sine-wave input.

Overall gain: AM4/503, 0 dB $\pm 0 \cdot 05$ dB.
AM4/504, 3 dB $\pm 0 \cdot 05$ dB.

Gain stability, $\pm 0 \cdot 05$ dB for $\pm 6\%$ change in mains voltage.

Output Separation

AM4/503: Greater than 40 dB at 3 Mc/s.
Greater than 50 dB at 10 kc/s.

AM4/504: Greater than 37 dB at 3 Mc/s.
Greater than 47 dB at 10 kc/s.

Hum Voltage

Hum voltage (peak-to-peak), less than 1 mV.

Effect of Sudden Mains-voltage Variations

Signal excursion due to sudden change in mains voltage of $\pm 6\%$ is less than ± 100 mV for the AM4/503 and less than ± 150 mV for the AM4/504.

Response Measurements

Amplitude/frequency response, $\pm 0 \cdot 05$ dB to 5 Mc/s.

Group delay variation, ± 5 ns. to 5 Mc/s.

Differential phase shift, less than $0 \cdot 1$ degrees at $2 \cdot 7$ Mc/s.

50-c/s response: sag on 50-c/s square wave less than $1 \cdot 5\%$ for AM4/503 and less than 2% for AM4/504.

Low-frequency impulse response: less than 20% overshoot for d.c. step signal fed through any time constant.

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